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RESEARCH MEMORANDUM

PRELIMINARY INVESTIGATION OF A VARIABLE MASS-FLOW SUPERSONIC NOSE INLET

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PRELIMINARY INVESTIGATION OF A VARIABLE MASS-FLOW SUPERSONIC NOSE INLET

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SUMMARY

A method has been analyzed for varying the mass flow of supersonic inlets having a circular cross section and a central body. The method consists of changing the size of the entering stream tube by means of an inflatable boot on the surface of the central body. Tests were made at a Mach number of 2.70 to determine the effect of such nose shapes on the entering flow, mass flow, and pressure recovery. Comparison was made between theoretical and experimental mass flows. The test results show that the mass flow could be reduced to 76 percent of design mass flow without a large loss of pressure recovery and without the unstable flow conditions or discontinuities of the flow that exist in the fixed-geometry diffusers when similar reductions in mass flow are made by increasing the back pressure. Although drag measurements were not made in this investigation, consideration of shock-wave configurations indicates that the accompanying increase in drag is smaller than that caused by the strong shock waves ahead of the inlet which usually accompany reductions in mass flow made by increasing the back pressure.

INTRODUCTION

From the performance characteristics of ram jets operating at supersonic velocities it can be shown that for effective operation over a range of flight conditions, regulation of the mass flow is desirable. For a fixed-geometry supersonic nose inlet of the type having a circular cross section and a central body and having part internal and part external supersonic compression, the mass flow cannot be reduced with supersonic entering air. Theoretically it is possible to reduce the mass flow by increasing the back pressure until the internal supersonic compression is eliminated and a new flow condition is established. This new flow condition is established suddenly and is accompanied by an abrupt decrease of mass flow and an increase in drag. Figure 1 shows the two flow conditions for a fixed-geometry inlet and illustrates the

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asymmetrical flow condition which may exist due to uneven separation on the central body. The result is asymmetrical loading of the inlet. Since this flow condition is unstable, the mass flow cannot be reduced sufficiently without the flow oscillations and vibrations becoming of such magnitude that this method cannot ordinarily be used. The mass flow may also be regulated by moving the central body forward along the axis of the inlet. Since the central body usually houses fuel, instruments, and accessories, this system is sometimes not desirable.

In the present discussion a method is introduced by which the mass flow is regulated by changing the nose angle of the central body. In order to reduce the mass flow entering the inlet, the flow must be deflected so that some of the flow does not enter the inlet. If the shock wave produced by the central body is either made stronger or moved forward, some of the air which would otherwise enter the inlet is deflected around it. By increasing the nose angle of the central body the shock wave is made stronger and, at the same time, moves outward away from the lip of the cowling. This may possibly be accomplished by attaching to the central body a flexible boot which may be inflated to increase the nose angle. The purpose of this preliminary investigation is to determine the effect of such a method on the entering flow, mass flow, and pressure recovery, and to compare the experimental mass flow with the theoretical.

The tests were made at the Langley Laboratory in an intermittent jet used for previous tests of similar supersonic inlets. The Mach number was 2.70 and the Reynolds number 2.5×10^6, based on the cowling-lip diameter.

SYMBOLS

θ_b equivalent cone angle; angle between axis of diffuser and line joining apex of cone and tangent to surface of inflated boot

θ_c semicone angle of central body

θ_e effective cone angle; semicone angle of a central body with a conic shape which would produce a shock wave tangent to that of a given θ_b

θ_l cowling position parameter; angle between axis of diffuser and line joining apex of cone to lip of cowling

P_o initial stagnation pressure

P_f stagnation pressure after deceleration into inlet

R radius of entering stream tube

DESCRIPTION OF THE METHOD

The method of mass-flow regulation considered in this preliminary investigation concerns the variation of the effective nose angle of the central body. This variation can be effected by the use of a flexible boot incorporated in the surface of the central body. By inflating the boot the effective nose angle can be increased. The general shape of such an inflated boot is shown to an exaggerated scale in figure 2. The inflated portion is not extended all the way to the apex of the central body on the assumption that in actual practice it would be necessary to fasten the flexible material some distance back from the tip.

The effect of the change in nose angle on the flow is shown in figure 3. With the boot uninflated, the entering stream tube is represented by streamline BC. The radius of the entering stream tube is shown as R. As the boot is inflated the cone angle is, in effect, increased, and the shock wave OA moves to a new position OA'. Now the streamline under consideration, BC, is deflected at C' and does not enter the inlet, and no longer represents the entering stream tube. Streamline B'C" now represents the entering stream tube, although it is also deflected by shockwave OA', but at a different point C", and enters the inlet. The radius of the entering stream tube is now shown as R', which is smaller than R. Thus, it has been shown that an increase of the central-body nose angle will result in a decrease in mass flow.

In order to give some basis for comparing the data obtained from the tests, a parameter which is an indication of the amount of inflation of the boot is introduced. This parameter, the equivalent cone angle θ_b, is the angle formed by the axis of the inlet and a line drawn from the tip of the central body and tangent to the surface of the inflated boot.

For comparison with the experimental data the mass flow entering the inlet for reduced mass-flow conditions was calculated by assuming that the central body was a true cone with the semi-apex angle equal to the equivalent angle θ_b. The shapes of the streamlines in the conical field were drawn from data taken from reference 1, and the comparative sizes of the entering stream tube were determined graphically. This method gives only an approximation of the mass flow. For a more precise solution, not included in this preliminary investigation, the flow field can be calculated by applying the method of characteristics (reference 2) to the exact central-body nose shapes.

APPARATUS AND MODEL

The apparatus used for testing and the method of acquiring data are fully described in reference 3. The mass flow was measured with a calibrated thin plate orifice contained in a tube attached to the rear of the model.

The entrance diameter of the cowling was 1.50 inches, with 4° internal and 7° external lip angles.

In order to simulate the inflated bodies, the nose of the central body was built up with soft solder and shaped as follows: The added solder was first cut to the maximum diameter of the central body and then cut to form a conic shape with the semi-apex angle equal to the equivalent cone angle with the apex of the cone coincident with the original nose. The solder was then removed from the nose for a distance of 1/4 inch back from the tip, and the remaining material was cut to form a faired curve along the surface. The result is the shape of the simulated boot of the desired equivalent angle. The exact shape within the dimensional limits given was not considered critical. The central-body location was kept constant at the position which placed the shock wave from the nose of the central body at the cowling lip with a 22° central body at a Mach number of 2.70.

DISCUSSION AND RESULTS

An analysis of the flow entering the inlet was made assuming that the apex angle of the central body increased but that the nose of the central body was still a true cone. Since the inflated boot was started some distance back from the tip of the central body, the actual shape is not a cone; therefore, if this analysis is to be used for the comparison of experimental data, the agreement of the equivalent cone angle θ_b with the effective cone angle θ_e must be determined. The comparison of θ_b and θ_e is presented in figure 4, and shows reasonably close agreement. In figure 5, the calculated and measured values of mass flow are compared in terms of relative mass flow, defined as the ratio of the actual mass flow to the mass flow for the design condition.

Excluding the value at $\theta_b = 27.25$, the experimental results show reasonable agreement with the theory assuming a true cone for the values of θ_b. At 27.25° the marked deviation from the theory may possibly be caused by the effects of the appreciable difference between the contour of the central body with the simulated boot and the true conical shape assumed in the theory. Only at this value of θ_b do the effects from expansion of the flow over the simulated boot, as observed in figure 6, cause noticeable curvature of the shock ahead of the inlet.

The effect of reduction of mass flow by this method on the pressure recovery is shown in figure 7. For relative mass flow of 90 percent, the loss of pressure recovery from the value of 67.7 for design mass flow is of the order of 7 percent, while that for 80-percent relative mass flow is of the order of 9 percent. For relative mass flow of 76 percent the pressure recovery was reduced to 56.9. These values of loss of pressure recovery are small enough to allow this system to be practical.

Shadowgraphs of the flow condition presented in figure 6 show that the external flow does not undergo any large or abrupt changes with change of equivalent cone angle θ_b. There is an increase in the strength of the shock wave which indicates an increase in drag, but this increase is gradual. The strength of the shock wave is less than that of the inlet with a normal shock across the entrance and, therefore, the drag is less than if the mass flow is reduced by increasing the back pressure until a normal shock wave is formed. There is no indication of any unstable flow conditions which might cause flow oscillations.

CONCLUSIONS

A method for varying the mass flow of supersonic inlets having a circular cross section and a central body has been considered, and tests and calculations have been made in order to determine the effects at a Mach number of 2.70 of a simulated inflatable boot on the central-body surface upon the entering flow, mass flow, and pressure recovery. A comparison was made between experimental and theoretical mass flows.

The following conclusions were made:

1. The mass flow was decreased gradually to 76 percent of design mass flow with an accompanying decrease of pressure recovery from 67.7 percent for design mass flow to 56.9 percent.

2. The mass-flow reduction was achieved without the necessity of having a moving central body and without the unstable flow conditions, the accompanying vibrations, and abrupt change in drag produced by decreasing the mass flow with a fixed-geometry inlet.

3. For mass-flow reductions to 76 percent of the design mass flow it was found that the mass flow and shock angles could be predicted by theory assuming the central body to be represented by a cone tangent to the inflated boot.

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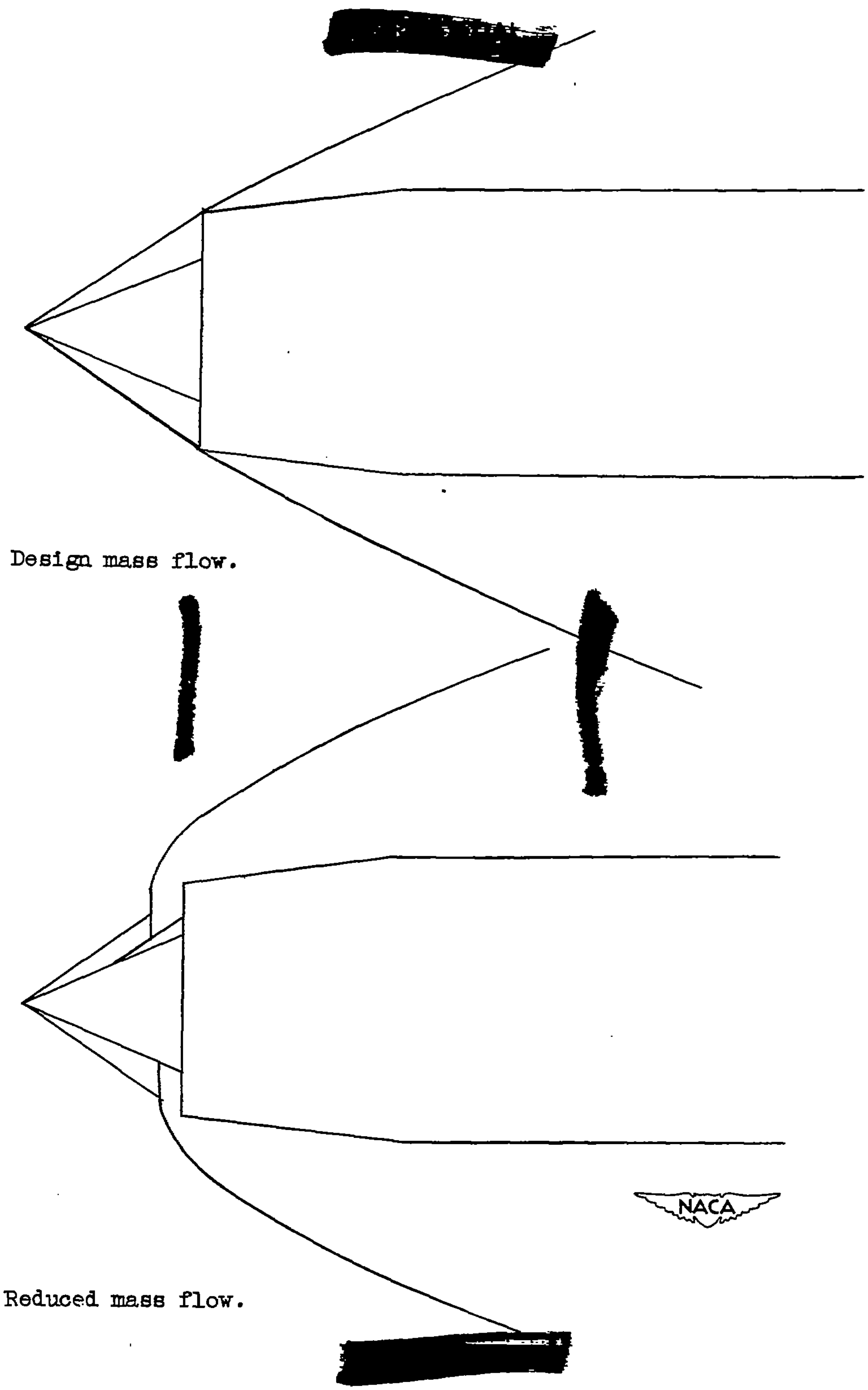

(a) Design mass flow.

(b) Reduced mass flow.

Figure 1.- Two flow conditions for fixed-geometry inlets.
(Not to scale.)

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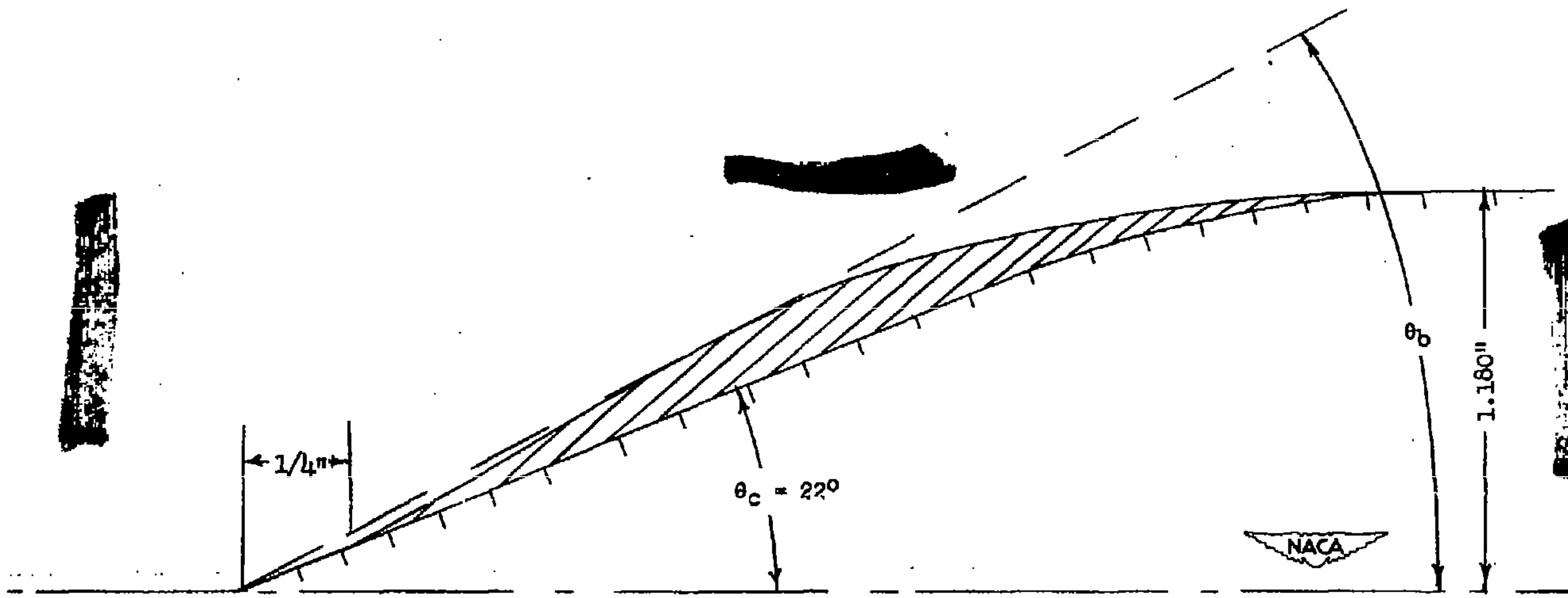

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Figure 2.- Typical shape of the simulated boot. (Not to scale.)

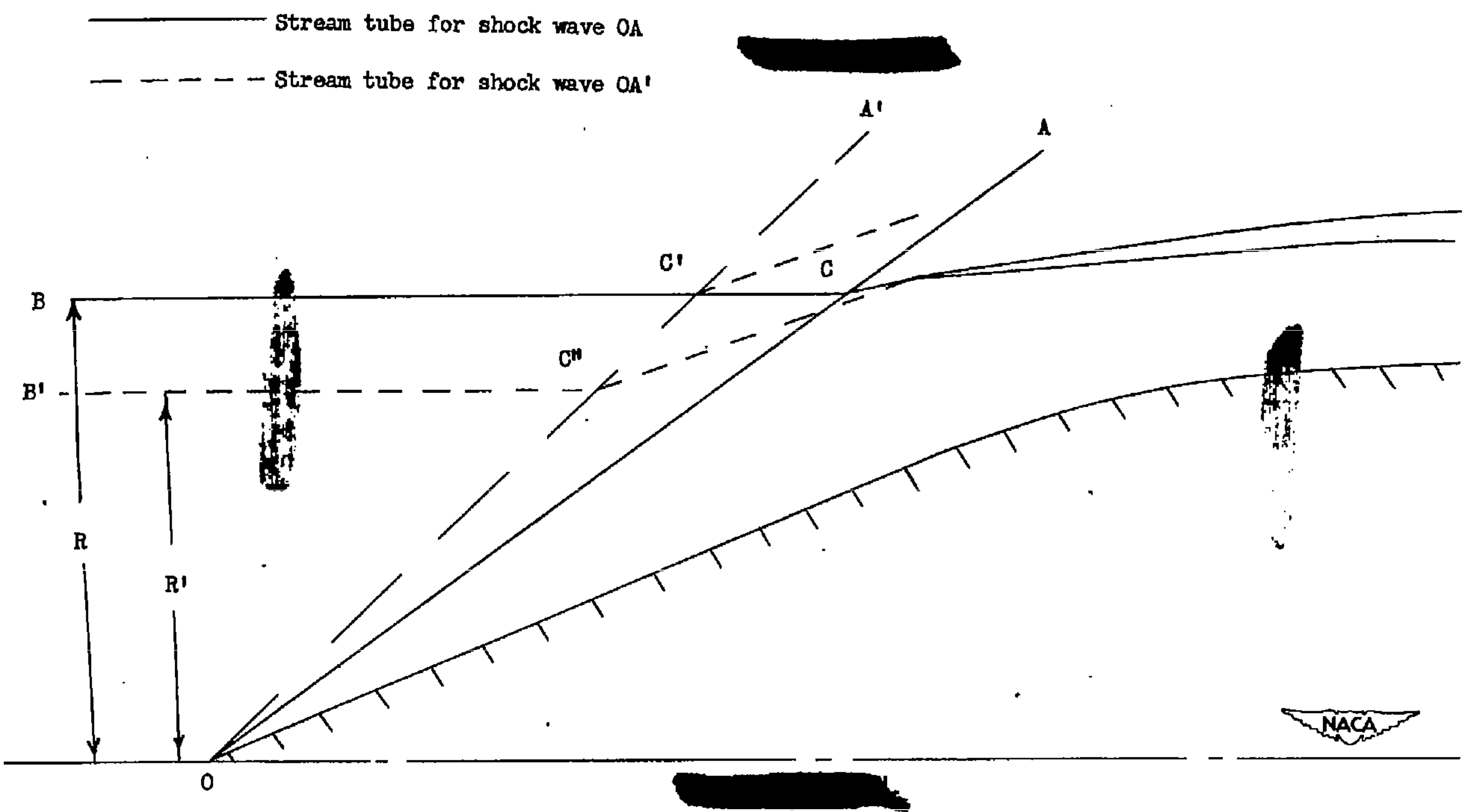

Figure 3.- Flow phenomena into inlet for two positions of the shock wave. (Not to scale.)

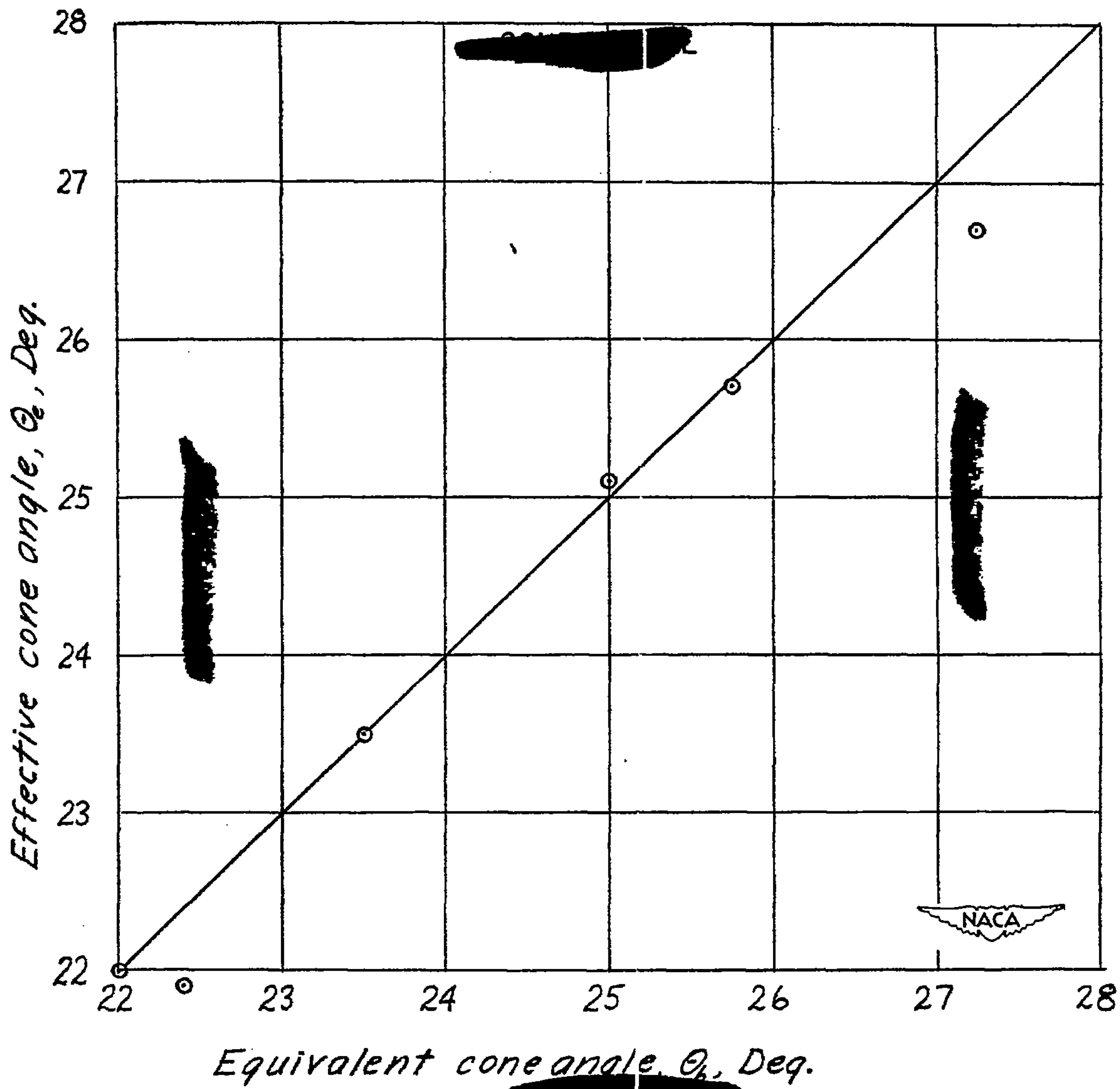

Figure 4.- Effective cone angle as a function of the equivalent cone angle.

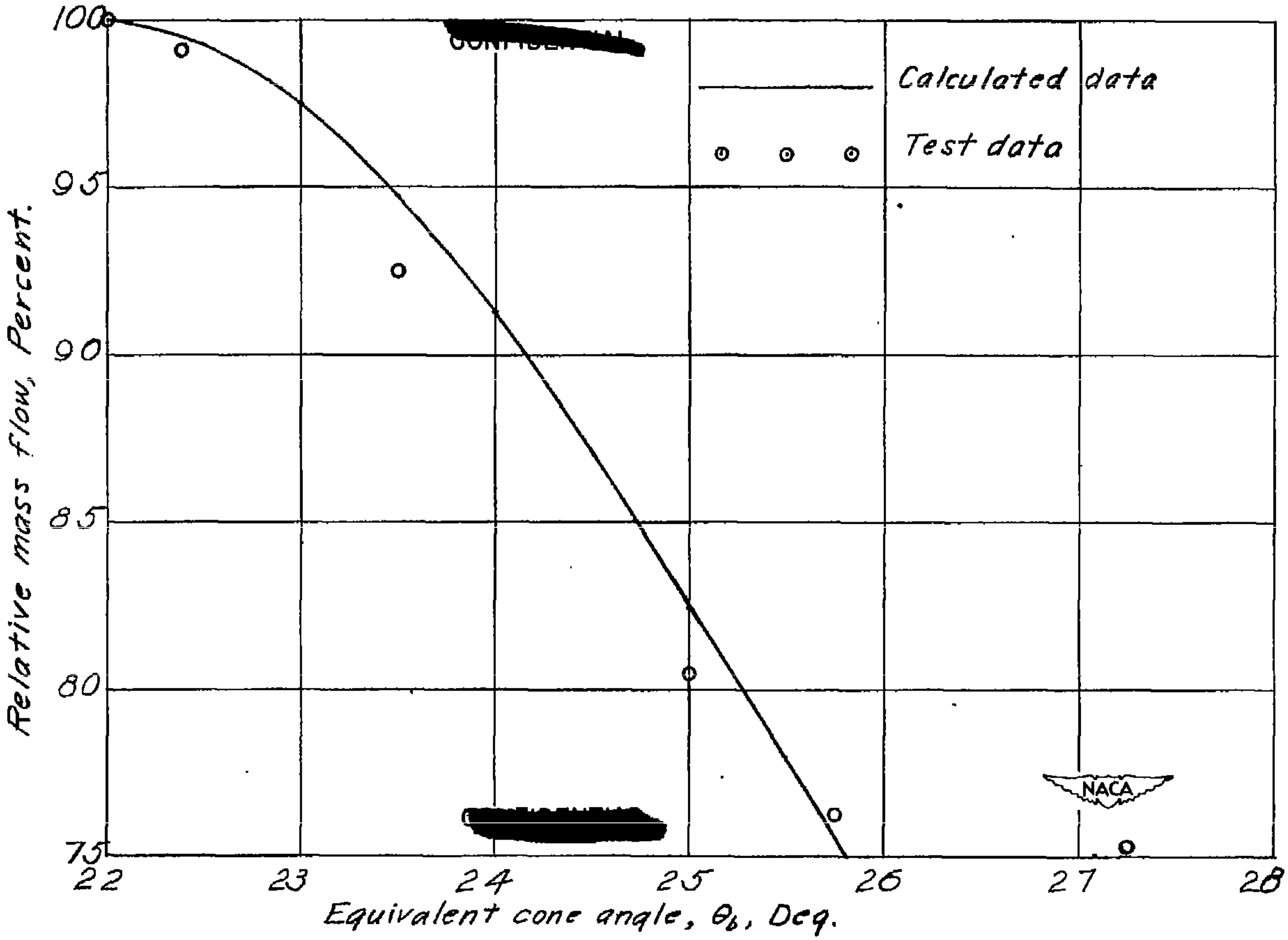

Figure 5.- Relative mass flow as a function of equivalent cone angle.

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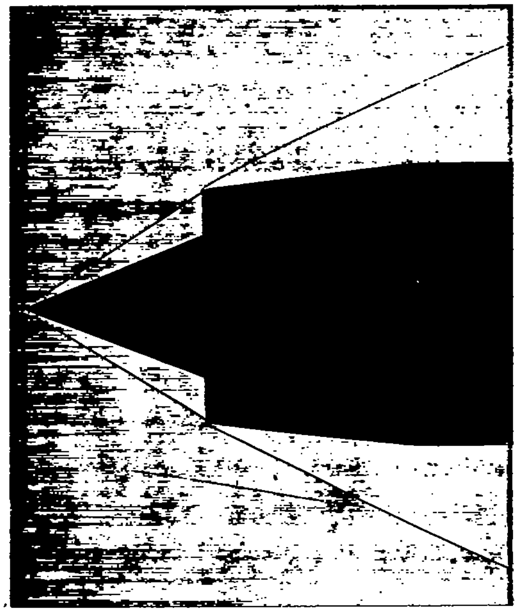
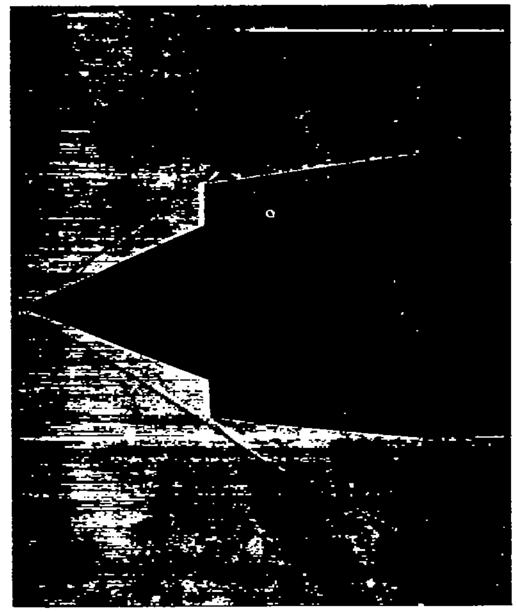
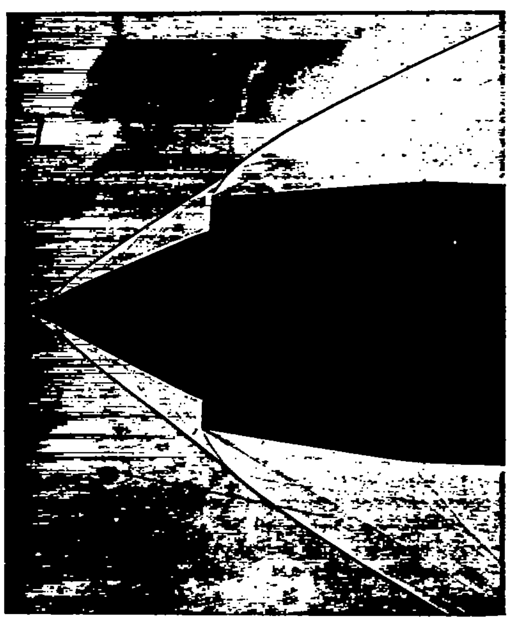


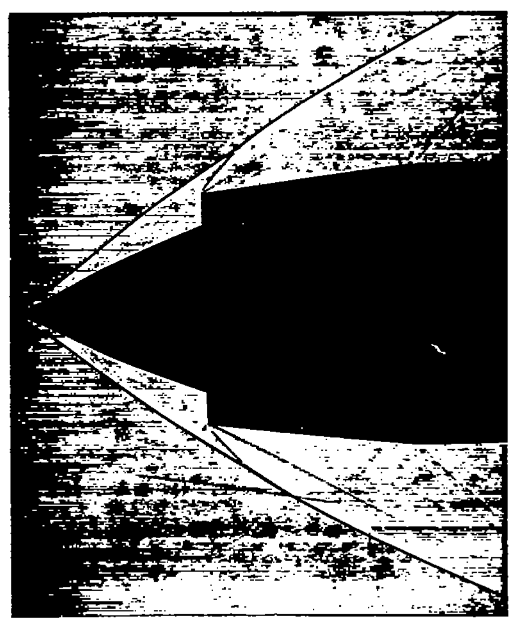
Relative mass flow = 1.00.



Relative mass flow = 0.93.



Relative mass flow = 0.76.



Relative mass flow = 0.75.

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Figure 6.- Shadowgraph pictures of the inlet for four different values of relative mass flow.

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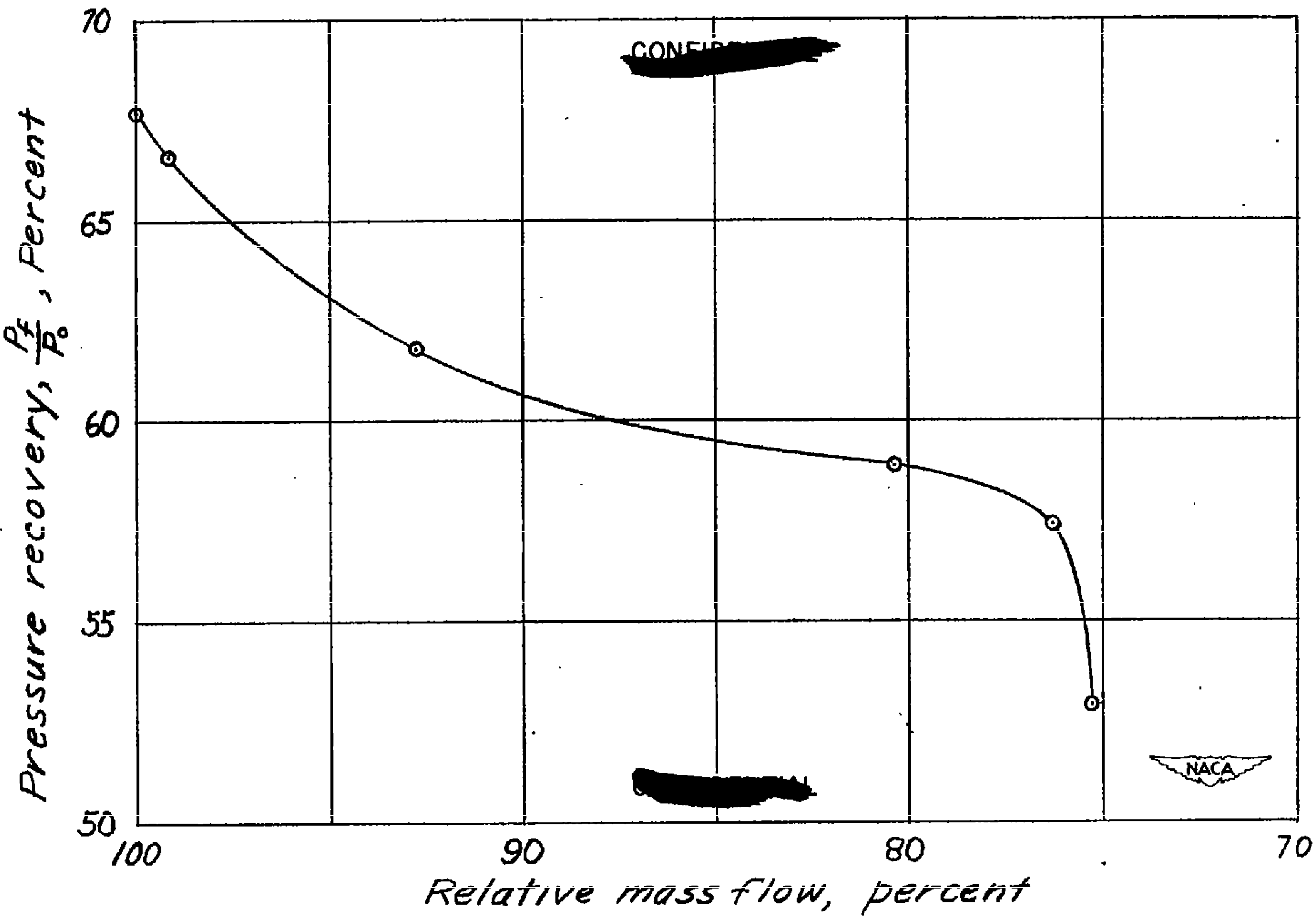

Figure 7.- Pressure recovery as a function of relative mass flow.

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